JACC Vol. 25, No. 4
March 15, 1995:855–65

Clinical and Lesion Morphologic Determinants of Coronary Angioplasty Success and Complications: Current Experience

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Objectives. **This study evaluated the validity of the American College of Cardiology/American Heart Association ABC lesion classification scheme and its modifications.**

Background. **With the continued refinement in angioplasty technique and equipment evolution, the lesion morphologic determinants of immediate angioplasty outcome have changed significantly. Hence, the validity of the classification scheme has been questioned.**

Methods. **We assessed the lesion morphologic determinants of immediate angioplasty outcome in 729 consecutive patients who underwent coronary angioplasty of 994 vessels and 1,248 lesions.**

Results. **Angioplasty success was achieved in 91% of lesions, and abrupt closure occurred in 3%. Success was achieved in 96%, 93% and 80% of type A, B and C lesions, respectively (A vs. B, p = NS; B vs. C, $p < 0.001$; A vs. C, $p < 0.001$; A vs. B1, p = NS; A vs. B2, $p = 0.03$; B1 vs. B2, $p = 0.02$; B2 vs. C, $p < 0.001$; C1 vs. C2, p = NS). Abrupt closure occurred in 2.1%, 2.6% and 5% of type A, B and C lesions, respectively (A vs. B, B vs. C, A vs. C and A vs. B1, all p = NS; B1 vs. B2, $p = 0.01$; B2 vs. C1, p = NS; C1 vs. C2, $p = 0.04$). Type B characteristics had a success rate ranging from 74% to 95% and an abrupt closure rate ranging from 2.2% to 14%. Type C characteristics had a success rate ranging from 57% to 88% and an abrupt closure rate ranging from 0% to 16%. Longer lesions, calcified lesions, diameter stenosis of 80% to 99% and presence of thrombus were predictive of a lower success rate. Longer lesions, angulated lesions, diameter stenosis of 80% to 99% and calcified lesions were predictive of an abrupt closure.**

Conclusions. **The previously proposed classification schemes are outdated and need to be changed for application in current angioplasty practice. Analyzing specific lesion morphologic characteristics rather than applying a simple lesion classification score when evaluating angioplasty outcome may be more useful because it provides a more precise profile of the lesion and allows better patient stratification and selection.**

(J Am Coll Cardiol 1995;25:855–65)

Since the introduction of percutaneous transluminal coronary angioplasty, multiple preprocedural clinical and angiographic characteristics have been identified as determinants of immediate angioplasty outcome (1–5). On the basis of these observations, the American College of Cardiology/American Heart Association (ACC/AHA) Task Force issued guidelines to make recommendations regarding the appropriate selection of patients for this therapeutic procedure (6). They proposed a classification scheme based on the morphologic characteristics of lesions to estimate the likelihood of early angioplasty success and complications, which were subsequently modified by Ellis et al. (7) and Myler et al. (8). These classification schemes have proved to be a useful guide for operators in assessing the likelihood of success and risk of complications for a particular lesion, thus assisting in appropriate case selection.

Despite inclusion of more complex cases, the continued refinement in balloon angioplasty technique, greater operator experience and equipment evolution have led to improved early angioplasty outcome (9–13). Currently, only a minority of lesions treated with coronary angioplasty have a morphology that would be considered ideal. Two recent reports, one from the National Heart, Lung, and Blood Institute Percutaneous Transluminal Coronary Angioplasty Registry (14) and the other from the Cleveland Clinic Foundation (13), confirmed the expanded indications for this procedure and documented the improved success rate despite an increased complexity of cases. Further advances in angioplasty technology have occurred since that period. As a result, the early angioplasty outcome for all types of lesions has changed, and the applicability of these classification schemes in the setting of current angioplasty practice has been questioned.

The present study had three objectives: 1) to assess the early results of coronary balloon angioplasty in a recent cohort of patients; 2) to evaluate the validity of previously proposed ACC/AHA and modified classification schemes; and 3) to undertake a comprehensive assessment of clinical and lesion morphologic characteristics to assess the impact of each individual characteristic on early angioplasty success and complications and identify independent determinants of early angioplasty outcome.

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Manuscript received June 13, 1994; revised manuscript received October 12, 1994, accepted October 27, 1994.

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0735-1097/95/$9.50
0735-1097(94)00462-Y

Methods

Study patients. Between January 1990 and March 1993, 729 consecutive patients (mean [±SD] age 57 ± 9 years, range 25 to 83; 562 [77%] men, 167 [23%] women) underwent coronary angioplasty of 994 vessels and 1,248 lesions. Patients who underwent directional atherectomy or stent implantation as the primary procedure were excluded from the study. However, patients who had stent implantation as a rescue procedure after balloon angioplasty were included and were classified as having a failed balloon angioplasty with complications.

A previous myocardial infarction had occurred in 387 patients (53%), resulting in left ventricular dysfunction (ejection fraction <45% as assessed by contrast ventriculography) in 227 (31%). One hundred thirty-nine patients (19%) had previous coronary artery bypass graft surgery. Emergency coronary angioplasty was performed in 153 patients with unstable angina (21%). Before intervention, 418 patients (57%) had grade III or IV angina, assessed by the Canadian Cardiovascular Society functional classification (15). Two hundred eighty-two patients (39%) had single-vessel disease, and 447 (61%) had multivessel disease. Risk factors present included hypertension (18%), diabetes mellitus (7.8%), hypercholesterolemia (50%) and current smoking (30%).

Angioplasty procedure. Coronary angioplasty was performed according to a previously described protocol (16). Throughout the study period, adaptations were made to accommodate technical advances, such as the development of low profile conformable balloons (polyethylene terephthalate). The routine use of long balloons (30 to 40 mm) for dilating long and angulated lesions and perfusion balloons for prolonged dilation of proximal lesions gained wide acceptance by all operators only during the latter part of the study period.

Study methods. Baseline clinical and angiographic characteristics of all 729 patients were assessed. All angiographic details were assessed by two independent observers without previous knowledge of angioplasty outcome. If there was any disagreement, the opinion of a third experienced cardiologist was obtained. Hand-held calipers and protractors were used for making quantitative measurements from the projected angiographic film, using the image of the guiding catheter for magnification scaling. Lesion complexity was scored as type A, B or C according to the guidelines published by the ACC/AHA Task Force (Table 1) (6). Type B and C lesions were further subcategorized as suggested by Ellis et al. (7) and Myler et al. (8) (types B1 and C1 = one adverse characteristic; types B2 and C2 = two or more adverse characteristics).

Definitions. The following definitions were used.

Bifurcation lesion. Lesion involving the bifurcation of a large epicardial coronary artery. Side branches were either protected or unprotected (with no guide wire or balloon catheter placed in the side branch).

Calcification. Presence of radioopacity at the site of the stenosis before contrast medium injection.

Dissection. Presence of angiographically evident intimal or medial damage defined according to the National Heart, Lung, and Blood Institute criteria (17,18): *type A* = nonpersistent radiolucent areas within the lumen of the vessel (tear or flap); *type B* = parallel tracts caused by extravasation of nonpersisting contrast medium; *type C* = extravasation of persisting contrast medium; *type D* = spiral lumen filling defect with delayed runoff of contrast; *type E* = new, persistent lumen filling defects with delayed anterograde flow; *type F* = filling defect accompanied by total coronary occlusion.

Distal ectasia. Evidence of abnormal arterial segment expansion beyond the stenosis.

Eccentricity. A ≥75% displacement of the lumen within the lesion in any projection by visual assessment (lumen in the outer one-quarter diameter of the apparent normal lumen).

High grade stenosis. Lesion with a lumen diameter narrowing of 80% to 99% relative to the adjacent normal coronary artery dimension.

Lesion length. This was measured from the proximal to distal shoulder of the lesion in the least foreshortened projection using calipers. Lesions were classified as *discrete* (<10 mm), *tubular* (10 to 20 mm) or *diffuse* (>20 mm).

Table 1. Classification of Coronary Artery Lesions

American College of Cardiology/American Heart Association Task Force Classification	
Type A lesions (high success >85%; low risk)	
Discrete (<10 mm length)	Little or no calcification
Concentric	Less than totally occlusive
Readily accessible	Not ostial in location
Nonangulated segment (<45°)	No major branch involvement
Smooth contour	Absence of thrombus
Type B lesions (moderate success, 60% to 85%; moderate risk)	
Tubular (10–20 mm length)	Moderate to heavy calcification
Eccentric	Total occlusions <3 mo old
Moderate tortuosity of proximal segment	Ostial in location
Moderately angulated segment (>45°, <90°)	Bifurcational lesions requiring double guide wires
Irregular contour	Some thrombus present
Type C lesions (low success, <60%; high risk)	
Diffuse (>20 mm length)	Total occlusion >3 mo old
Excessive tortuosity of proximal segment	Extremely angulated segments >90°
Degenerated vein grafts with friable lesions	Inability to protect major side branches
Modified Scheme	
Ellis et al. (7)	
Type B1 lesion	One adverse type B characteristic
Type B2 lesion	Two or more adverse type B characteristics
Myler et al. (8)	
Type C1 lesion	One adverse type C characteristic
Type C2 lesion	Two or more adverse type C characteristics

Lesion angulation. The vessel angle formed by a centerline through the lumen proximal to the stenosis and extending beyond it, and a second centerline in the straight portion of the artery distal to stenosis. Lesions were classified as *nonangulated* (<45°), *moderately angulated* (45 to 90°) or *extremely angulated* (>90°).

Lesion contour. Presence or absence of irregularities or "sawtooth" appearance on the lumen surface of the stenosis.

Lesion success. A ≤50% residual diameter stenosis at the dilated site without an abrupt closure. In the event of an abrupt occlusion, even if the reestablishment of flow was possible with prolonged balloon inflation, the lesion was still classified as having had an abrupt closure.

Ostial lesion. A lesion involving the coronary ostium arising within 0.3 cm of the aortic orifice (left main stem and right coronary artery ostial stenoses) or left main stem (left anterior descending, circumflex or intermediate ostial stenoses).

Procedural success. This occurred when a patient had at least one vessel successfully dilated without a major complication (death, Q wave myocardial infarction or emergency coronary artery bypass grafting) at any time during the hospital period (invariably the result of an abrupt occlusion of the vessel being dilated).

Tandem lesion. Sequential lesions in different segments of the artery separated by angiographically disease-free segments.

Thrombus. Presence of intraluminal filling defects or contrast medium staining within the lumen.

Tortuosity. Lesion accessibility was classified as readily *accessible* (no or one bend >45° proximal to the stenosis), *moderately tortuous* (presence of two bends >45° proximal to the lesion) or *excessively tortuous* (presence of more than two bends >45° proximal to the stenosis).

Total occlusion. This was defined as 100% lumen diameter narrowing with absence of a visible intraluminal channel. The duration of occlusion was estimated either from the date of myocardial infarction in the distribution of the occluded vessel, abrupt worsening of angina pectoris or information provided by sequential angiograms.

Unstable angina pectoris. Angina occurring at rest requiring intravenous medical therapy, including postinfarction angina pectoris.

Vessel success. Successful dilation of all lesions with lumen diameter narrowing >50% present in the vessel without an abrupt occlusion.

Statistical methods. Continuous variables are expressed as median value (interquartile range) because of their nonnormal distribution, with the exception that the patients' ages are expressed as mean value (SD). The study patients, vessels and lesions were classified into subgroups, both according to initial angioplasty outcome and whether an untoward event had occurred. The clinical and angiographic variables analyzed as possible correlates of early angioplasty outcome were compared for each of these outcomes. Categoric variables were compared using the chi-square test or the two-sided Fisher exact test; $p < 0.05$ was considered statistically significant.

All variables found to be significantly related to early angioplasty outcome by univariate analysis were included in a multiple logistic regression analysis. The backward stepwise selection procedure was used to identify independent predictors of early angioplasty outcome significant at the 1% level (using BMDP program LR). Analyses were performed with and without the modified ACC/AHA classification scheme (8) included as a predictive variable. Data concerning the technical details of the procedure were also compared: between the ACC/AHA lesion subtypes, between occluded and nonoccluded lesions and between calcified and noncalcified lesions using nonparametric tests.

Results

Procedural results. Of the 729 patients, 202 (28%) underwent multivessel coronary angioplasty, and 323 (44%) underwent multilesion coronary angioplasty. A mean of 1.4 vessels and 1.7 stenoses per patient were dilated.

Procedural outcome. Procedural success was achieved in 657 patients (90.1%). A major in-hospital complication occurred in 24 patients (3.3%). Three patients (0.4%) died; 5 (0.7%) had a Q wave myocardial infarction; and 15 (2.1%) underwent emergency coronary artery bypass graft surgery. One patient (0.1%) underwent stent implantation for abrupt vessel closure without any untoward clinical sequelae.

Predictors of procedural outcome. The clinical variables that were analyzed to assess their association with procedural outcome are shown in Table 2. Multiple logistic regression analysis identified the presence of triple-vessel disease ($p = 0.016$) and unstable angina ($p < 0.001$) as independent predictors of a lower procedural success. Unstable angina emerged as the only independent predictor of procedural complication ($p = 0.009$).

Vessel results. Coronary angioplasty was attempted in 994 vessels. The vessels dilated, the number of lesions dilated in each vessel and the lesion morphologic combinations are shown in Tables 3 and 4.

Vessel outcome. Angioplasty success was achieved in 888 vessels (89.3%). An abrupt occlusion occurred in 24 vessels (2.4%).

Predictors of vessel outcome. The effects of vessel location, number of lesions dilated in each vessel and lesion morphologic combinations on early angioplasty outcome are shown in Tables 3 and 4. There was no significant correlation between vessel location or number of lesions dilated in each vessel and early angioplasty outcome. Vessel success was lower for those with type C lesions (77%) or C-C combinations (75%).

Lesion results. Coronary angioplasty was attempted in 1,248 lesions, of which 1,157 were nonoccluded, and 91 were totally occluded.

Lesion success. Angioplasty success was achieved in 1,132 lesions (91%). An abrupt closure occurred in 38 lesions (3%).

Evaluation of ACC/AHA and modified schemes. The relation between the ACC/AHA classification scheme or its modifications and early angioplasty outcome is shown in Table 5. Early angioplasty success was achieved in 96%, 93% and 80%

Table 2. Clinical Characteristics Predictive of Procedural Success, Uncomplicated Angioplasty Failure and Complications (based on all 729 patients)

	No. of Pts	Success	p Value	UAF	p Value	Compl.	p Value
Gender							
Male	562	511 (91)	NS	34 (6.0)	NS	17 (3.0)	NS
Female	167	146 (87)		14 (8.4)		7 (4.2)	
Angina grade IV							
Yes	230	204 (89)	NS	14 (6.1)	NS	12 (5.2)	0.05
No	499	453 (91)		34 (6.8)		12 (2.4)	
Previous MI							
Yes	387	343 (89)	NS	29 (7.5)	NS	15 (3.9)	NS
No	342	314 (92)		19 (5.6)		9 (2.6)	
Previous CABG							
Yes	139	121 (87)	NS	16 (12)	0.009	2 (1.4)	NS
No	590	536 (91)		32 (5.4)		22 (3.7)	
Abnormal LV							
Yes	227	198 (87)	NS	18 (7.9)	NS	11 (4.8)	NS
No	502	459 (91)		30 (6.0)		13 (2.6)	
Emergency procedure							
Yes	153	127 (83)	<0.001	14 (9.2)	NS	12 (7.8)	<0.001
No	576	530 (92)		34 (5.9)		12 (2.1)	
No. of diseased vessels							
One	282	263 (93)		14 (5.0)		5 (1.8)	
Two	245	220 (90)	0.03	13 (5.3)	0.04	12 (4.9)	NS
Three	202	174 (86)		21 (10)		7 (3.5)	
Smoking							
Yes	218	191 (88)		17 (7.8)		10 (4.6)	
No	137	120 (88)	NS	12 (8.8)	NS	5 (3.6)	NS
Ex-smoker	374	346 (93)		19 (5.1)		9 (2.4)	
Diabetes mellitus							
Yes	57	53 (93)	NS	4 (7.0)	NS	0 (0)	NS
No	672	604 (90)		44 (6.5)		24 (3.6)	
Family history							
Yes	282	253 (90)	NS	18 (6.4)	NS	11 (3.9)	NS
No	447	404 (90)		30 (6.7)		13 (2.9)	
Hypertension							
Yes	133	118 (89)	NS	8 (6.0)	NS	7 (5.3)	NS
No	596	539 (90)		40 (6.7)		17 (2.9)	
Hypercholesterolemia							
Yes	366	333 (91)	NS	21 (5.7)	NS	12 (3.3)	NS
No	363	324 (89)		27 (7.4)		12 (3.3)	

Data presented are number (%) of patients (Pts). CABG = coronary artery bypass grafting; Compl. = complications; LV = left ventricular function; MI = myocardial infarction; UAF = uncomplicated failure.

of type A, B and C lesions, respectively (A vs. B, $p = 0.13$; B vs. C, $p < 0.001$; A vs. C, $p < 0.001$). Comparison of success rates between the lesion subtypes showed the following: A versus B1 ($p = 0.69$); A versus B2 ($p = 0.03$); B1 versus B2 ($p = 0.02$); B2 versus C ($p < 0.001$); C1 versus C2 ($p = 0.15$).

An abrupt closure occurred in 2.1%, 2.6% and 5.0% of type A, B and C lesions, respectively (A vs. B, $p = 0.8$; B vs. C, $p = 0.06$; A vs. C, $p = 0.11$). Comparison of abrupt closure rate between the lesion subtypes showed the following: A versus B1 ($p = 0.46$); B1 versus B2 ($p = 0.01$); B2 versus C1 ($p = 0.92$); C1 versus C2 ($p = 0.04$).

Effect of lesion morphology on lesion outcome. The correlation between specific lesion morphology and early angioplasty outcome is shown in Table 6. Univariate analysis of 13 lesion morphologic features showed that early angioplasty success was less common with longer lesions, highly angulated lesions, lesions containing calcium and lesions containing thrombus. Abrupt closure was also more common with longer lesions, highly angulated lesions, calcified lesions and lesions containing thrombus.

Effect of stenosis severity on lesion outcome. The effects of lesion severity on early angioplasty outcome are summarized in Table 7. Coronary angioplasty of total occlusions was associated with a lower early success rate than occluded lesions. However, the abrupt closure rate was also lower. Occlusions that were ≥3 months old (type C lesions) had a lower early success rate than occlusions <3 months old (type B lesions). In nonoccluded lesions, when the subgroups of lesion severity

Table 3. Angioplasty Success and Complications According to Lesion Location (based on 994 target vessels)

Lesion Location	No. of Target Vessels	Success	UAF	Abrupt Closure
LMCA	6	6 (100)	0 (0)	0 (0)
LAD	390	346 (89)	27 (7)	17 (4)
INT	16	16 (100)	0 (0)	0 (0)
Cx	268	242 (90)	23 (9)	3 (1)
RCA	255	226 (89)	26 (10)	3 (1)
SVG/IMA	59	52 (88)	6 (10)	1 (2)
Total	994	888 (89)	82 (8)	24 (2)

Data presented are number (%) of vessels. Cx = circumflex coronary artery; INT = intermediate coronary artery; LAD = left anterior descending coronary artery; LMCA = left main coronary artery; RCA = right coronary artery; SVG/IMA = saphenous vein graft/internal mammary artery graft; UAF = uncomplicated failure.

were compared, significant differences in the early success and abrupt closure rates were found between high grade stenoses (80% to 99%) and all other subgroups.

Independent determinants of lesion outcome. Excluding total occlusions, multiple stepwise logistic regression analysis identified increased lesion length, calcified lesions, high grade stenoses and presence of thrombus as independent predictors of early angioplasty failure (Table 8). Increased lesion length, increased lesion angulation, high grade stenoses and calcified lesions emerged as independent predictors of an abrupt closure (Table 9). When the modified ACC/AHA classification scheme was forced in the regression model, calcified lesions, high grade stenoses and presence of thrombus were still independently predictive of early angioplasty failure. The same independent predictors of an abrupt closure were retained. With these models, the probability of early angioplasty success and abrupt closure for a particular lesion can thus be estimated.

Effect of angiographic dissection on abrupt closure. Of the 1,157 nonoccluded lesions, angiographically visible dissection was seen in 221 (19%) after balloon dilation. Severity of dissection was classified according to the National Heart, Lung, and Blood Institute criteria: 171 were type A or B, and 50 were type C to F. Presence of a dissection was a strong predictor of abrupt closure (8.1% vs. 2.1%, $p < 0.001$). However, when the dissection morphologic subtypes were compared, a significant difference in the abrupt closure rate was found between type A and B dissections and all other subtypes. Type A and B dissections were not associated with an increased risk of abrupt closure when compared with lesions without angiographic dissection (1.2% vs. 2.1%, $p = 0.56$). The increased abrupt closure rate was a result of type C to F dissections (32% vs. 2.1%, $p < 0.001$).

Technical considerations. The technical variables involved during coronary angioplasty are presented in Table 10. Type C lesions required more frequent inflations than type A or B lesions. Occluded lesions required more frequent inflations and a longer inflation duration than nonoccluded lesions. Calcified lesions not only required more frequent inflations and a longer inflation duration, they also needed a higher inflation pressure than noncalcified lesions. The balloon/artery ratio did not differ significantly between the various subgroups and was not predictive of an abrupt closure (<0.9 = 2.2%; 0.9 to 1.1 = 1.2%; >1.1 = 2.0%, $p = 0.54$). Mean balloon/artery ratio was 1.02 (SD 0.14) in lesions with an abrupt closure and 1.03 (SD 0.14) in lesions without ($p = 0.83$).

Table 4. Angioplasty Success and Complications According to Number of Lesions Dilated in Each Vessel and Lesion Morphologic Combinations (based on all 994 target vessels)

	No. of Target Vessels	Success	UAF	Abrupt Closure
No of lesions dilated in each vessel				
1	804	713 (89)	73 (9.1)	18 (2.2)
2	142	132 (93)	7 (4.9)	3 (2.1)
3	36	34 (94)	1 (2.8)	1 (2.8)
4	10	7 (70)	1 (10)	2 (20)
6	2	2 (100)	0 (0)	0 (0)
Lesion combination				
A	125	119 (95)	5 (4.0)	1 (0.8)
B1	216	198 (92)	12 (5.6)	6 (2.8)
B2	259	233 (90)	20 (7.7)	6 (2.3)
C1	186	152 (82)	30 (16)	4 (2.1)
C2	18	11 (61)	6 (33)	1 (5.6)
A-A	4	4 (100)	0 (0)	0 (0)
A-B	32	29 (91)	1 (3.1)	2 (6.3)
A-C	2	2 (100)	0 (0)	0 (0)
B-B	74	72 (97)	2 (2.7)	0 (0)
B-C	14	13 (93)	1 (7.1)	0 (0)
C-C	16	12 (75)	3 (19)	1 (6.3)
Mainly A	5	4 (80)	1 (20)	0 (0)
Mainly B	42	38 (90)	1 (2.4)	3 (7.1)
Mainly C	1	1 (100)	0 (0)	0 (0)
Total	994	888 (89)	82 (8)	24 (2)

Data presented are number (%) of vessels. Abbreviations as in Tables 2 and 3.

Table 5. Effect of American College of Cardiology/American Heart Association Classification Scheme and Its Modifications on Angioplasty Outcome (based on 1,248 target lesions)

Lesion Morphology	No. of Lesions	Success	UAF	Abrupt Closure
A	193	185 (96)	4 (2.0)	4 (2.1)
B	794	737 (93)	36 (4.5)	21 (2.6)
C	261	210 (80)	38 (15)	13 (5.0)
A	193	185 (96)	4 (2.0)	4 (2.1)
B1	369	351 (95)	14 (3.8)	4 (1.1)
B2	425	386 (91)	22 (5.2)	17 (4.0)
C1	240	196 (82)	34 (14)	10 (4.2)
C2	21	14 (67)	4 (19)	3 (14)
Total	1,248	1,132 (91)	78 (6.3)	38 (3.0)

Data presented are number (%) of lesions. Abbreviations as in Tables 2 and 3.

Table 6. Effect of Individual Lesion Morphology on Angioplasty Outcome (based on 1,157 nonoccluded lesions)

Lesion Morphology	No. of Lesions	Success	p Value	UAF	p Value	Abrupt Closure	p Value
Length							
<10 mm	959	907 (95)		38 (4.0)		14 (1.5)	
10–20 mm	153	130 (85)	<0.001	6 (3.9)	NS	17 (11)	<0.001
>20 mm	45	35 (78)		3 (6.7)		7 (16)	
Eccentric							
Yes	666	615 (92)	NS	26 (3.9)	NS	25 (3.8)	NS
No	491	457 (93)		21 (4.3)		13 (2.6)	
Tortuosity							
No	965	898 (93)		38 (3.9)		29 (3.0	
Moderate	142	132 (93)	NS	4 (2.8)	NS	6 (4.2)	NS
Severe	50	42 (84)		5 (10)		3 (6.0)	
Angulation							
<45°	991	928 (94)		41 (4.1)		22 (2.2)	
45–90°	136	119 (88)	0.005	5 (3.7)	NS	12 (8.8)	<0.001
>90°	30	25 (83)		1 (3.3)		4 (13)	
Contour							
Smooth	762	712 (93)	NS	29 (3.8)	NS	21 (2.8)	NS
Irregular	395	360 (91)		18 (4.6)		17 (4.3)	
Calcium							
Yes	81	60 (74)	<0.001	10 (12.3)	<0.001	11 (14)	<0.001
No	1,076	1,012 (94)		37 (3.4)		27 (2.5)	
Ostial							
Yes	77	72 (94)	NS	5 (6.5)	NS	0 (0)	NS
No	1,080	1,000 (93)		42 (3.9)		38 (3.5)	
Bifurcation							
No	970	900 (93)		37 (3.8)		33 (3.4)	
Protected	135	128 (95)	NS	4 (3.0)	0.018	3 (2.2)	NS
Unprotected	52	44 (85)		6 (12)		2 (3.8)	
Thrombus							
Yes	46	34 (74)	<0.001	8 (17)	<0.001	4 (8.7)	0.036
No	1,111	1,038 (93)		39 (3.5)		34 (3.1)	
Vein graft lesion							
Yes (<3 yr)	17	16 (94)		1 (5.9)		0 (0)	
Yes (>3 yr)	41	36 (88)	NS	2 (4.9)	NS	3 (7.3)	NS
No	1,099	1,020 (93)		44 (4.0)		35 (3.2)	
Lesion location							
Proximal	533	488 (92)		31 (5.8)		14 (2.6)	
Mid	501	465 (93)	NS	15 (3.0)	0.01	21 (4.2)	NS
Distal	123	119 (97)		1 (0.8)		3 (2.4)	
Distal ectasia							
Yes	42	38 (90)	NS	1 (2.2)	NS	3 (6.7)	NS
No	1,115	1,034 (93)		46 (4.1)		35 (3.1)	
Tandem lesions							
Yes	450	425 (94)	NS	13 (2.9)	NS	12 (2.7)	NS
No	707	647 (92)		34 (4.8)		26 (3.7)	

Data presented are number (%) of lesions. UAF = uncomplicated failure.

Discussion

The guidelines and classification scheme proposed by the ACC/AHA Task Force reflected angioplasty experience and opinions between 1986 and 1988. Since that time there have been dramatic advances in balloon angioplasty technology and techniques (9–13). Lesions that were previously considered unfavorable for the procedure are now increasingly attempted. As a result, the influence of specific clinical and lesion morphologic characteristics on early angioplasty outcome has changed significantly.

Two studies have formally examined the validity of the ACC/AHA classification scheme, one representing angioplasty experience between 1986 and 1987 (7) and the other between 1990 and 1991 (8). The present study reports on an extensive and more recent experience.

Table 7. Effects of Lesion Severity on Angioplasty Outcome

Lesion Severity	No. of Lesions	Success	p Value	UAF	p Value	Abrupt Closure	p Value
Occlusions							
No	1,157	1,072 (93)	<0.001	47 (4.0)	<0.001	38 (3.3)	0.05
Yes	91	60 (66)		31 (34)		0 (0)	
<3 mo	42	32 (76)	0.05	10 (24)	0.05	0 (0)	NA
≥3 mo	49	28 (57)		21 (43)		0 (0)	
Stenosis							
80–99%	726	648 (89)	<0.001	42 (5.8)	<0.001	36 (5.0)	<0.001
51–79%	431	424 (98)		5 (1.2)		2 (0.5)	

Data presented are number (%) of lesions. NA = not applicable; UAF = uncomplicated failure.

Effect of clinical variables on angioplasty outcome. The procedural success and complication rates achieved in the present study are similar to those recently reported (7,8,14). Clinical presentation with unstable angina was strongly correlated with adverse procedural outcome. Previous balloon angioplasty studies in patients with unstable angina have reported procedural success rates ranging from 61% to 93% and complication rates from 2% to 20% (19–22). Although the underlying pathologic change is spontaneous plaque fissuring or rupture (23), there is no universally accepted clinical definition. Hence, previous studies have included patients with a wide variety of clinical presentations, and this may be the cause for the disparate results reported.

Apart from the presence of triple-vessel disease, none of the other clinical characteristics analyzed was found to be associated with procedural outcome despite associations shown in previous studies. This probably reflects improved case selection in these high risk patients on the basis of knowledge gained from previously published reports.

Effect of stenosis location on angioplasty outcome. In the present study, neither vessel nor lesion location emerges as an important variable in determining the early outcome of coronary angioplasty. Although earlier studies have shown unfavorable results in the dilation of stenoses located in the left circumflex coronary artery or at distal sites (5), relatively nonsteerable angioplasty equipment was used in those days. More recently, Savage et al. (24) reported that right coronary artery location significantly reduced the primary success rate. Hermans et al. (25) also reported a significantly higher dissection rate in right coronary artery lesions. The present study does not support these findings.

Effect of lesion morphology on angioplasty outcome. Of all the morphologic characteristics that were cited in the ACC/AHA classification scheme, only increased lesion length, lesion calcification and presence of thrombus were identified as independent predictors of early angioplasty failure. Increased lesion length, increased lesion angulation and lesion calcification were predictive of an abrupt closure. Although high grade stenosis was not included in the original classification, its presence significantly reduced the likelihood of angioplasty success and increased the likelihood of an abrupt closure in the present series. Even with the modified ACC/AHA classification scheme included in the regression analyses, similar results were obtained, indicating that these variables were highly important correlates of early angioplasty outcome.

Lesion length. Because longer lesions have a larger amount of atherosclerotic material, dissections and abrupt closure occur more readily (26). The adverse impact of increased lesion length has been shown by previous investigators (3,4,27–29). However, recent reports from Ellis et al. (7) and Savage et al. (24) have not shown any correlation between lesion length and early angioplasty outcome. This may in part be attributed to the increasing use of long balloons, which would allow the entire diseased segment to be adequately covered, thus reducing the incidence of dissection (30–32).

Lesion angulation. The adverse influence of lesion angulation on early angioplasty outcome has also been shown by

Table 8. Multiple Stepwise Logistic Regression Model to Predict Lesion Success (based on 1,157 nonoccluded lesions)

Variable	Coefficient	SE	OR	95% CI for OR	p Value
Length					
10–20 mm	−0.79	0.28	0.45	0.26–0.79	
>20 mm	−1.24	0.41	0.29	0.13–0.64	0.001
Calcium	−1.33	0.30	0.27	0.15–0.48	<0.001
Thrombus	−1.28	0.38	0.28	0.13–0.58	0.002
High grade stenosis	−1.65	0.41	0.19	0.09–0.43	<0.001

CI = confidence interval; OR = odds ratio.

Table 9. Multiple Stepwise Logistic Regression Model to Predict Absence of Abrupt Closure (based on 1,157 nonoccluded lesions)

Variable	Coefficient	SE	OR	95% CI for OR	p Value
Length					
10–20 mm	−1.80	0.39	0.16	0.08–0.35	
>20 mm	−2.33	0.52	0.10	0.03–0.27	<0.001
Angulation					
45–90°	−1.39	0.41	0.25	0.11–0.55	
>90°	−1.91	0.64	0.15	0.04–0.52	<0.001
Calcium	−1.19	0.42	0.30	0.13–0.69	0.007
High grade stenosis	−1.99	0.74	0.14	0.03–0.59	<0.001

Abbreviations as in Table 8.

Table 10. Technical Data for the 1,132 Successfully Dilated Lesions

Lesion	Pre-PTCA Stenosis (%)	Post-PTCA Stenosis (%)	Inflation			B/A Ratio
			Frequency	Pressure (atm)	Duration (s)	
Type						
A	82	11	2	6	180	1.03
	(72–90)	(4–18)	(2–3)	(6–8)	(120–240)	(0.93–1.12)
B	83	14	2	7	180	1.02
	(75–91)	(8–22)	(2–3)	(6–8)	(120–240)	(0.93–1.10)
C	87	14	3	7	180	1.00
	(78–97)	(7–26)	(2–4)	(6–8)	(120–270)	(0.93–1.10)
p value	<0.001	<0.001	0.04	0.56	0.18	0.37
Occluded						
Yes	100	13	3	8	240	0.98
	(100–100)	(10–31)	(2–5)	(6–8)	(180–360)	(0.91–1.09)
No	83	13	2	7	180	1.02
	(74–90)	(8–21)	(2–3)	(6–8)	(120–240)	(0.93–1.10)
p value	<0.001	0.007	0.001	0.41	<0.001	0.20
Calcified						
Yes	86	18	3	8	180	1.02
	(81–92)	(8–31)	(2–4)	(6–10)	(135–300)	(0.96–1.11)
No	83	12	2	6	180	1.02
	(74–92)	(8–21)	(2–3)	(6–8)	(120–240)	(0.93–1.10)
p value	0.04	0.02	0.001	<0.001	0.007	0.55
Total	83	13	2	7	180	1.02
	(75–92)	(8–22)	(2–3)	(6–8)	(120–244)	(0.93–1.10)

Data presented are median value (interquartile range). B/A = balloon/artery; Pre-PTCA (Post-PTCA) = before (after) percutaneous transluminal coronary angioplasty.

previous investigators (2,4,7,25,29). The underlying mechanism appears to be arterial dissection from noncoaxial stress caused by the straightening of the angulated atherosclerotic segment when the balloon catheter is inflated. There has been growing enthusiasm for the use of long balloons in treating angulated lesions. Longer balloons appear to have better conformability, and favorable results on their use have been reported (32). Polyethylene terephthalate balloons may also confer superior conformable properties, which reduces straightening stress and risk of dissection (29). Last, a balloon with a preshaped angle of 135° to 145° at its midportion has also been developed, which may reduce straightening of the angled segment (30,33). The routine use of long balloons has gained wide acceptance at our institution only during the latter part of the study period. This may explain the unfavorable outcome in lesions with angulation of ≥90° in the present series.

Calcification. Calcified lesions, by virtue of their rigidity, often require multiple balloon inflations at higher pressures to eliminate the "waist" of the stenoses. Animal studies (34) have shown that vessels exposed to high inflation pressure had a significantly higher incidence of mural thrombus, dissection and medial necrosis. Furthermore, if the burst pressure is exceeded, rupture of the balloon catheter can lead to extensive coronary dissection. These factors may have led to the unfavorable outcome observed in the present and previous studies (5,8,24,28). Polyethylene terephthalate balloons have a low compliance and allow a very high inflation pressure, with little overexpansion of the balloons. Reports on the use of these balloons in calcified lesions have shown encouraging results (35,36).

Thrombus. Preexisting intracoronary thrombus has been shown to pose an increased risk for angioplasty (4,8,24,27,37–39). Although the frequency of occurrence in the present study was low (<4%), its presence was strongly correlated with unsuccessful angioplasty and abrupt closure. Virtually all of the intracoronary thrombus seen in the present study occurred in patients who presented with unstable angina (23,40). The mechanism of early vessel closure is probably thrombus propagation due to balloon trauma to the vessel wall, exposing collagen and thrombotic factors, and the release of vasoactive substances (41). Aggressive periprocedural antiplatelet and anticoagulant therapy has been shown to reduce the risk of abrupt occlusion in some studies (38,42) but not all (39).

Stenosis severity. In the present study, the presence of a high grade stenosis reduces the chance of success and increases the risk of abrupt closure, confirming previous findings (5,7,17,24,27). Coronary angioplasty of total occlusions, especially those that were ≥3 months old, was associated with a significantly lower success rate but also a lower risk of complication. The longer the duration of occlusion, the more the lesion is organized with fibrous tissue and the likelihood of recanalization becomes less.

Evaluation of ACC/AHA and modified schemes. *Angioplasty success.* Because 79% were either type A or B lesions, the ACC/AHA classification scheme was unable to stratify the majority of the lesions according to the probability of success. There was no difference in the success rate between type A and

B lesions, and both were associated with a success rate of >90%. However, type C lesions had a significantly lower success rate of 80%. The modified scheme, by subtyping type B lesions, was able to identify a subgroup of type B2 lesions with a significantly lower success rate than type A or B1 lesions. Although further subtyping of type C lesions identified a subgroup of type C2 lesions, of which only 67% were successfully dilated, this was not significantly different from the success rate achieved with type C1 lesions. Hence, the modified scheme, as suggested by Ellis et al. (7), appears to provide useful lesion stratification into categories of high (types A and B1, ≥95%), intermediate (type B2, 91%) and low (type C, 80%) probability of success. However, lesions that were categorized as having an intermediate probability of success (type B2) were nevertheless associated with a success rate >90%. Lesions that were categorized as having a low probability of success (type C) had a success rate of 80%, which is much higher than the 60% suggested by the ACC/AHA Task Force.

Angioplasty complications. In the present series, the ACC/AHA classification scheme provided a poor stratification of lesions into risk groups of abrupt closure. There was no difference in the abrupt closure rate among type A, B or C lesions. However, the modified scheme, by subtyping type B lesions, identified a subgroup of type B2 lesions with a significantly higher abrupt closure rate than type B1 lesions. Further subtyping of type C lesions identified a subgroup of type C2 lesions with a significantly higher abrupt closure rate than type C1 lesions. Hence, the modified scheme, as suggested by Myler et al. (8), provided useful stratification of lesions into categories with low (types A and B1, ≤2.1%), intermediate (types B2 and C1, ≤4.2%) and high (type C2, 14%) risk of abrupt closure. Although both the low and intermediate risk categories were associated with an abrupt closure rate of <5%, the high risk lesions had an unacceptable abrupt closure rate of 14%.

Hence, the present study suggests that the ACC/AHA classification scheme is outdated, perhaps because of improvement in angioplasty technique and equipment evolution. The modified schemes appear to allow useful stratification of stenoses into categories with significantly different, albeit closely related, outcomes. However, the lesion subtypes stratified according to probability of success and those according to risk of abrupt closure did not correlate with each other. Furthermore, although listed under the same category in the ACC/AHA classification scheme, the impact of each individual morphologic characteristic on angioplasty outcome is not equal. In this series, type B characteristics were associated with success rates ranging from 74% (calcified stenosis) to 95% (protected bifurcation stenosis) and abrupt closure rates ranging from 2.2% (protected bifurcation stenosis) to 14% (calcified stenosis). Similarly, type C characteristics were associated with success rates ranging from 57% (chronic occlusions) to 88% (old saphenous grafts) and abrupt closure rates ranging from 0% (chronic occlusions) to 16% (lesion length >20 mm).

Effect of angiographic dissection on abrupt closure. Although coronary angioplasty results in an angiographically visible dissection in 20% to 45% (18,43) of the stenoses dilated, ischemic complications occur in only 4% to 11% of cases (4,6,27,44). However, given the grave consequences that are associated with abrupt closure, and the availability of new treatment modalities (45,46), the ability to predict the likelihood of major ischemic complications could have important clinical implications. Previous studies (47,48) have indicated that in the presence of an angiographic dissection, residual stenosis, dissection length and certain morphologic types of dissection are correlated with an adverse outcome. In the present study, morphologic type C to F dissections were associated with an increased incidence of abrupt closure, but not types A and B, as are consistent with the findings of Huber et al. (48). Hence, in conjunction with the patient's symptoms, electrocardiographic changes and hemodynamic status, the National Heart, Lung, and Blood Institute classification provides an additional method for guiding the management of patients with angiographic dissection.

Technical considerations. Despite the greater technical requirement, a less satisfactory final angiographic result was seen with calcified, totally occluded and type C stenoses, reflecting the complexity of these lesions. However, the pressures needed to dilate total occlusions were no different than those of nonoccluded lesions, suggesting that the consistency of occluded lesions was no different in the absence of calcification. In contrast to previous studies (49,50), the balloon/artery ratio was not correlated with angioplasty complications. This probably reflects careful balloon sizing by operators on the basis of the findings of previous investigators.

Study limitations. Although the present study reports on a nonselected, consecutive series of patients, it is a retrospective analysis of data and is subject to the limitations inherent in any retrospective study. The frequency of occurrence of some of the variables analyzed was low. Diabetes mellitus was present in only 53 patients (7%). Distal ectasia was present in only 42 lesions (3%), and only 58 (5%) were graft lesions. These variables may have been significant determinants of early angioplasty outcome had a greater number of patients been present in the study. Multiple subgroup comparisons were made, and the possibility of a type II statistical error should be acknowledged.

Conclusions. With currently available angioplasty technology, >90% of coronary stenoses can be successfully dilated with balloon angioplasty with an acceptable complication rate of <5%. The present study showed that the ACC/AHA and modified classification schemes, although useful tools in aiding patient stratification, need to be amended to be applicable to current angioplasty practice. First, the ascribed estimated success and risk for each category may need to be revised in light of the improved results achieved with recent technologic advances. Second, some of the original lesion characteristics listed in the ACC/AHA classification scheme may need to be deleted or recategorized, given the significant change in the morphologic predictors of early angioplasty outcome. Third, previously unconsidered lesion characteristics may need to be incorporated into the scheme in light of recent reports and the

present study. Even with these modifications, there exist multiple problems intrinsic to a classification scheme. Therefore, identifying and analyzing specific lesion morphologic characteristics, rather than applying a simple lesion classification score when evaluating angioplasty outcome, may be more useful because they provide a more precise profile of the lesion and allow better patient stratification and selection. In support of this, the present study has shown that the probability of early angioplasty success and complications can be predicted from easily identifiable lesion morphologic features. Careful case selection, with specific attention to these morphologic features, is all important in ensuring continued improvement in early angioplasty outcome.

New devices have recently been introduced as an alternative to balloon angioplasty for specific lesion characteristics, although the initial enthusiasm has diminished as experience was gained (51). There remain some morphologic characteristics where the current results from balloon angioplasty could be further improved. Whether these lesions should be treated with new balloon angioplasty technology or new devices (e.g., rotational atherectomy [52], directional atherectomy [53], laser angioplasty [54]) will need to be resolved by randomized trials. Until then, any new devices that may be introduced will need to be compared with this contemporary experience.

We thank Lisa Goodall, Sheila Karani and Ann Williamson for technical assistance and data collection.

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